ISTANBUL TECHNICAL UNIVERSITY
FACULTY OF NAVAL ARCHITECTURE AND OCEAN ENGINEERING

AN INVESTIGATION ON THE EFFECTS OF FUEL ADDITIVE ON THE PERFORMANCE AND EXHAUST EMISSIONS OF MARINE DIESEL ENGINES

FINAL REPORT

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ABSTRACT

The effects of fuel additive, CleanBoost Gold on the performance and exhaust emissions of a marine diesel engine installed on a ferry is investigated, experimentally. The fuel additive is based on a proprietary formula of Combustion Technologies USA that introduces a very small amount of highly purified catalysts into the fuel. The engine is a four-stroke, turbocharged, medium-speed diesel engine running on ultra-low-sulfur diesel (ULSD) fuel. The experiments were carried out on-board of the ferry, Ord. Prof. Ata Nutku sailing at Marmara Sea in Turkey. During the tests, NOx, SOx, CO, CO_2, HC and PM concentrations were measured at different engine loads for ultra low-sulfur diesel fuel with and without fuel additive. The shaft power, exhaust temperature, exhaust mass flow rate and ambient conditions were also measured. The experimental study was carried out using the facilities of ITU Ship Emission Laboratory*. The experimental results show that the use of the CleanBoost Gold fuel additive reduces the brake specific fuel-oil consumption by about 22.6% and the weighted emissions of NOx, CO_2, CO, SOx and unburned HC by about 24.8%, 22.9%, 17.4%, 54.5% and 12.2%, respectively. On the other hand, concentration of the O_2 and PM emissions increase by about 6.5% and 22.7 %, respectively. The SOx and PM emission values are found to be very low. This is as a result of using ultra-low sulfur diesel fuel. It can clearly be seen that the fuel additive, CleanBoost Gold improves the combustion process and decreases the NOx, CO, CO_2 and unburned HC emissions and brake specific fuel-oil consumption, substantially. Reducing fuel-oil consumption and exhaust emissions for a given voyage will not only provide financial benefit for the ship operator but also bring a positive impact on the environment and human health.

*) ITU Ship Emission Laboratory is one of the recognized laboratory by the Turkish Ministry of Transport and Infrastructure for the ship emission measurements.

1. INTRODUCTION

The shipping industry is responsible for the carriage of around 90% of world trade. Therefore, it is the nucleus of the global economy, but, is highly sensitive to fuel prices. Fuel costs represent around 50-60% of the total operating cost of a vessel and contribute a significant portion of the total transportation cost of cargo. Fluctuations in the price of crude oil and stricter environmental regulations on the emission of noxious and greenhouse gases are influential factors in the operation of the shipping industry (Argyros et al. (2014), Ergin (2011), Kim et al. (2014 and 2016), Murphy et al. (2012) and Ronen (1982)).

Exhaust emissions from the transportation are the main source of pollution and contribute to health problems and environmental impacts such as global warming, acidification, eutrophication and degradation of air quality (Cooper (2003), Corbett et al. (1999), Eyring (2005), Ergin et al. (2016 a-b), Kalender et al. (2017), Smith et al. (2014) and Viana et al. (2014)). Key compounds of exhaust emissions from shipping are the carbon dioxide (CO_2), carbon monoxide (CO), sulphur oxides (SOx), nitrogen oxides (NOx), volatile organic compounds (VOC), hydrocarbons (HC) and particulate matters (PM). To reduce the impact of these pollutant emissions from shipping, International Maritime Organization (IMO) MARPOL Annex VI convention regulates several pollutants, including carbon dioxide (CO_2) and nitrogen oxides (NOx) from newly built ships and sulphur oxides (SOx). Certain maritime regions are designated emission control areas (ECAs) where the regulated emission levels are lower than in the rest of the ocean.

The maximum allowed sulphur content in marine fuels will be 0.5% from 2020 and in sulphur emission control areas it is 0.1% from 2015. These limits will reduce the emissions of SO_2 but are also intended to reduce the emissions of PM since there is a dependence of fuel sulphur content for the PM emission factors. The NOx the emission limits are sharpened in a tiered system with Tier III being applied in NOx emission control areas for new engines from 2016 (North American NECA) or 2021 (Baltic and North Seas). Further, the emissions of greenhouse gases from shipping are growing and there is an urgent need for measures to break this trend. IMO has recently set a goal for greenhouse gas emissions from shipping to be reduced by 50% by 2050, compared with 2008-levels. IMO has also introduced the EEDI (energy efficiency design index) regulations in order to make new ships more fuel efficient. However, with an expected growth in maritime transport further measures are called for (see, for example, Bazari (2011), IMO (2009), IMO (2018) and Smith et al. (2014)).

There are several emission control methods and technologies. The sulphur regulations can be met by using low-sulphur fuel oils, such as marine gasoil (MGO), by using exhaust scrubbers, or by turning to other low-sulphur fuels such as liquefied natural gas (LNG) or methanol. To meet the Tier III NOx requirements, abatement methods such as selective catalytic reduction (SCR) can be used but engines using LNG can reach Tier III without exhaust abatement systems. The fuel additives are also promising solution to improve diesel engine performance and fuel economy and also decrease harmful exhaust emissions see, for example, Ergin et al. (2018), Karthikeyan et al. (2014), Ryu et al. (2016), Yanfeng et al. (2007) and Yang et al. (2016).

This study aims to investigate the effects of fuel additive, CleanBoost Gold on the performance and exhaust emissions of a marine diesel engine installed on the ferry, Ord. Prof. Ata Nutku, experimentally. The fuel additive is based on a proprietary formula of Combustion Technologies USA that introduces a very small amount of highly purified catalysts into the fuel (see, Restore Solutions (2019)). The engine is a four-stroke, turbocharged, medium-speed diesel engine running on ultra-low-sulfur diesel (ULSD) fuel. The experiments were carried out on-board of the ferry sailing at Marmara Sea between Eskihisar and Topçular in Turkey. During the tests, NOx, SOx, CO, CO_2, HC and PM concentrations were measured at different engine loads for ultra low-sulfur diesel fuel with and without fuel additive, CleanBoost Gold. The shaft power, exhaust temperature, exhaust mass flow rate and ambient conditions were also measured.

The experimental results show that the use of fuel additive, CleanBoost Gold reduces the weighted emissions of NOx, CO_2, CO, HC and SO_2 by about 24.8%, 22.9%, 17.4%, 12.2% and 54.5%, respectively. On the other hand, the O_2 concentration and PM emission values increased by about 6.5% and 22.7%, respectively when the fuel additive is used. Furthermore, the use of fuel additive reduces the weighted average brake specific fuel-oil consumption by about 22.6%.

2. EXPERIMENTAL STUDY

The experimental study was carried out on-board of the ferry, Ord. Prof. Ata Nutku sailing at Marmara Sea in Turkey. The ferry is 81m long with a tonnage of 1596 GRT and it was built in 2000. Table 1 shows the general properties of the ferry and the photo of the ferry is presented in Figure 1. She is fitted with two main engines which drive two controllable pitch propellers placed at the fore and aft of the ship. The main propulsion engine is a fourstroke, medium-speed and turbocharged diesel engine. Its main specifications are given in Table 2.

The measurements of NOx, SOx, CO, CO_2, HC and PM emissions for the main engine were taken by using the ultra-low-sulfur diesel fuel with and without fuel additive. The properties of diesel fuel with/without additive can be obtained in Appendix A. The fuel additive, CleanBoost Gold which is based on a proprietary formula of Combustion Technologies USA was added to the ultra low-sulfur diesel fuel with a ratio of 1:4000 or 250 ppm by volume. This ratio is taken as constant throughout the experimental study. This is recommended value for this type of the engine and fuel by the additive supplier (Restore Solutions (2019)). The tests without fuel additive were carried out from August 5th to 7th, 2019 and the tests with fuel additive from August 19th to 20th, 2019. The fuel additive was added to the fuel tanks of the ferry from August 8th, 2019 untill the end of the tests. Namely, the ULSD with fuel additive were used about 200 hours prior to the tests with fuel additive.

Figure 2 shows the experimental set-up for the emission measurements. As can be seen from Figure 2, the sampling port was placed on the exhaust stack at a distance from the main engine according to IMO NOx Technical Code. Emission measurements for different engine loads were carried out under the steady-state conditions using the E2 test cycle as shown in Table 3 (see, IMO (2009)).

The multi-gas analyzer Horiba PG-250 was used to measure the concentrations of NOx, SO_2, CO, O_2 and CO_2. Table 4 presents the measurement methods of Horiba PG250 gas analyser for

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the NOx, CO_2, SO_2, CO and O_2 emissions measurements. Horiba Mexa 1170 gas analyzer was employed to measure the unburned HC emissions. Its working principle is based on the Heated Flame Ionization Detection (HFID) method. This gas analyser has 14 measurement ranges between 0-10 ppm to 0-200,000 ppm. The calibration of the gas analysers were carried out using the certified calibration gases before and after the measurements.

For the PM emission measurements, the particle mass was collected by Tecora Isostack isokinetic sampling system which uses 47-mm-diameter glass-microfiber filters. The filters were dried by using the BINDER oven before the sampling. The samples were taken at nearly steady-state conditions for about 30 min ensuring the isokinetic flow rate. The particle mass was analyzed gravimetrically, and it was weighed before and after sampling using a Sortorius SE2F-Micro-Balance in the laboratory. The isokinetic deviation during the sampling was less than 10%, which is in accordance with the ISO 9096 standard.

Table 1. Vessel particulars.

General Properties of the Ferry	
IMO Number	9161144
Name	Ordinaryus Profesor Ata Nutku
Vessel Type	RO-RO/Passenger Ship
Gross Tonnage	1596
Summer DWT	225 t
Length Overall	80.71 m
Breadth Extreme	22 m
Year Build	2000
Flag	Turkey
Home port	Istanbul

Figure 1. Photo of the ferry, Ord. Prof. Ata Nutku (URL 1).

Table 2. Specifications of the main engine.

Main Engine	
Model	ABC 8MDX
Type	4-stroke, turbocharged, intercooled
Power	883 kW at 750 rpm
Cylinder arrangement	8 cylinder, in-line
Bore x Stroke	242 mm × 320 mm
Rod length	320
Swept volume	117.8 L
Compression ratio	12.06:1
Injection	Direct, mechanical, one pump per cylinder

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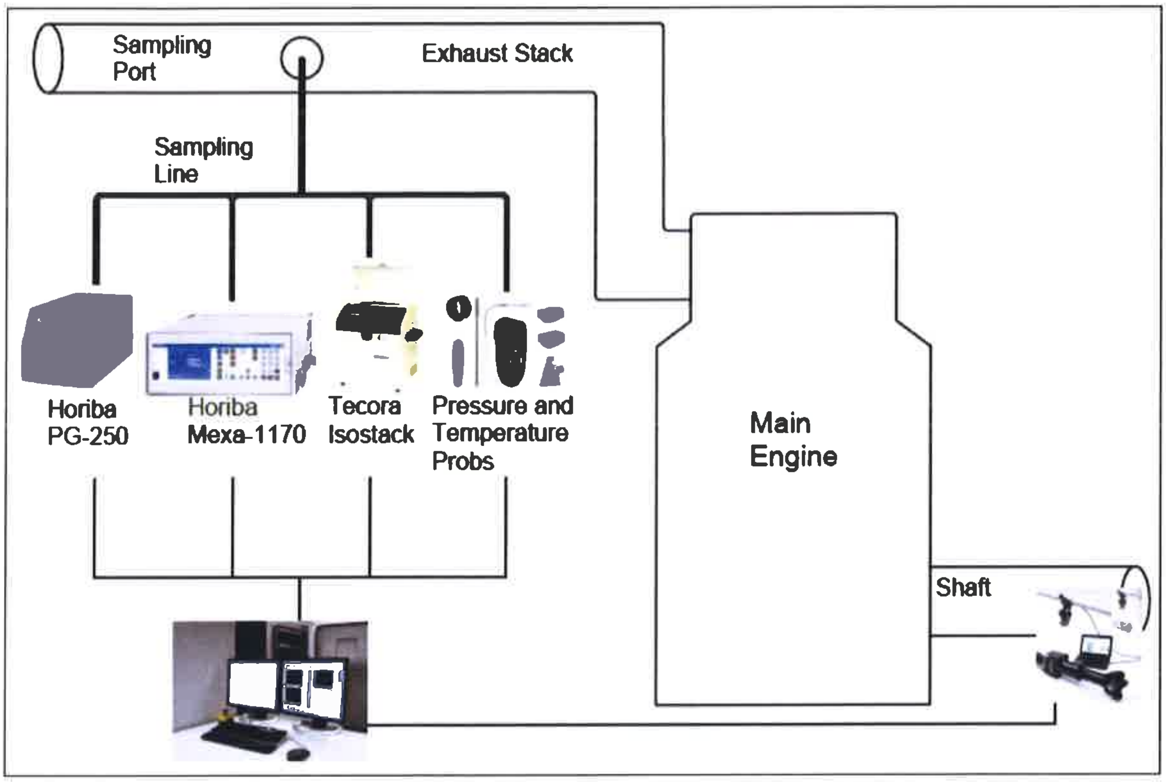

Figure 2. Experimental rig.

Table 3. The test cycle.

Test cycle E2				
Speed	100%	100%	100%	100%
Power	25%	50%	75%	100%
Weighting factor	0.15	0.15	0.5	0.2

Table 4. The measurement principle of HORIBA PG250 gas analyser.

HORIBA PG250 Gas Analyser		
Gas	**Measurement principle**	**Range**
O_2	Zirconium Oxide sensor	0~5/10/25 vol%
CO_2	Non-Dispersive Infrared absorption (NDIR)	0~5/10/20 vol%
NOx	Chemiluminescenc (CLD)	0~25/50/100/250/500/1000/2500 ppm
SO_2	Non-Dispersive Infrared absorption (NDIR)	0~200/500/1000/3000 ppm
CO	Non-Dispersive Infrared absorption (NDIR)	0~200/500/1000/2000/5000 ppm

The shaft power was measured by using Datum shaft power measurement system, which provides an output of shaft torque, shaft r/min and shaft power with an accuracy of 0.1%. During the measurements, first, the shaft power was set and monitored continuously. After that, sampling gas was taken from the stack and conveyed to the gas conditioning system and then to the gas analyzer. The sampling took around 30 min. Tests were repeated three times and the readings were averaged. The reduction gear losses were considered as 5%.

The fuel consumption of the engine was measured using the KROHNE 6300-Ultrasonic clamp-on flowmeter. The measurement system consists of a measuring sensor and a signal converter. The measuring sensor is fitted on the outside of piping to measure the flowrate of the fuel. The measurement principle of flow meter is based on the ultrasonic transit time.

During the tests, the temperature, humidity and differential pressure of the exhaust gases and the pressure, temperature and humidity of the ambient air were also measured.

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3. RESULTS AND DISCUSSION

The results of the experimental study which is carried out to investigate the effects of the CleanBoost Gold fuel additive on the performance and exhaust emissions of the marine diesel engine installed on the ferry Ord.Prof. Ata Nutku, are presented in Figures 3 to 13. The exhaust temperature and velocity values are presented in Figures 3 to 4. Figures 5-12 show the NOx, SO_2, CO, CO_2, HC and PM emissions, and O_2 concentration values for the fuel-oil with/without additive at different engine loads (25%, 50%, 75% and 100%). The results of the uncertainty analysis are also shown on Figures 3 to13 as error bars. Figure 13 presents the brake specific fuel-oil consumption values with and without fuel additive at different engine loads.

Figure 3 shows the measured exhaust temperatures of the engine operated with and without fuel additive at different engine loads of 25%, 50%, 75% and 100%. As can be seen from the figure, exhaust temperature increases as the engine load increases. The exhaust temperatures obtained with using fuel additive are lower than the exhaust temperatures obtained without using fuel additive. The difference between the exhaust temperatures with/without fuel additive decreases as the engine load increases. The maximum temperature difference of 8.4% is obtained at the lowest engine load, 25%.

The measured exhaust velocity values for the engine operated with/without fuel additive are presented at different engine loads in Figure 4. The exhaust velocity increases when the engine load increases. The velocity values for the case with fuel additive at the engine loads of 50% and 75% are higher than the velocity values without fuel additive by about 9.9 % and 1.4 %, respectively. On the other hand, they are lower at the engine loads of 25% and 100% by 9.8% and 6.7%, respectively.

The emission measurements are presented as emission factors (g/kW.h) which are based on the concentration of the measured exhaust pollutants, the measured engine power and the calculated exhaust flow rate. The main engine emissions of gas pollutants and particulate matter were calculated using the methodology given in the IMO NOx Technical code E2 test cycle.

Figure 5 presents the measured NOx emission values with and without fuel additive for different engine loads. The NOx emissions mainly depend on the combustion temperature, so generally they increase with the engine load. The NOx emission values with additive are lower than the NOx emission values without additive for the engine loads of 25%, 50%, 75% and 100% by about 40%, 19.2%, 22.2% and 26.8%, respectively. On the other hand, the weighted NOx emission values in Figure 5 shows that the weighted NOx emission with additive is about 24.8% less than the weighted NOx emission without additive. It can be said that the fuel additive reduces the NOx emissions, substantially.

The CO emissions occur as a result of incomplete combustion of fuel. Figure 6 shows the CO emissions with/without fuel additive for different engine loads. When the engine load increases, the CO emission first decreases and reaches to its minimum value then increases again. At high engine loads, it increases mostly due to the lack of oxygen. But, at low engine loads, it increases due to low temperatures in the combustion chamber which affect fuel atomization. The highest CO emission occurs at the lowest engine load of 25%. As can be seen from Figure 6, the use of fuel additive cause a reduction of 17.4% in the weighted average CO emissions. The maximum reduction in CO emission occurs at 50% engine load as about 27.2%.

Figure 7 presents the unburned HC emissions with and without fuel additive at different engine loads. In general, the emissions of unburned HC occur as a result of incomplete combustion of the hydrocarbon fuel. As the engine load increases, the unburned HC emission first decreases, then reaches its minumum value and then increases again. When the fuel additive was used the HC emissions are reduced for all engine loads. As can be seen from Figure 7, the reduction in the weighted average HC emission value with fuel additive is about 12.2 %. On the other hand, the maximum reduction in HC emission occurs at 75% load to be about 16.9%.

The effect of fuel additive on the CO_2 emissions can be clearly seen from Figure 8. The CO_2 emissions for all the engine loads reduce when the fuel additive is used. The reduction in the weighted average CO_2 emission is about 22.9 %. On the other hand, the maximum reduction in CO_2 emission occurs at 25% load as 35.7%. Generally, the amount of CO_2 emission increase with the engine load.

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The emissions of SO_2 are related to the fuel properties. The use of fuel additive resulted in lower emissions of SO_2 for all the engine loads except 25% load. The weighted SO_2 emission value with fuel additive is 54.5% less than the SO_2 emission value without fuel additive (see, Figure 9). This result should be evaluated carefully, since the SO_2 emission values are quite low due to using ultra low-sulfur diesel fuel. This also cause to have high uncertainty values for this case.

Figure 10 compares the total PM emissions with and without fuel additive at different loads. PM emissions mostly depend on sulfur content in the fuel. As can be seen from Figure 10, the PM emissions for all the loads are quite low. This is due to using ultra-low sulfur diesel fuel. The use of fuel additive increase the emissions of PM for all the engine loads except 25% load. The weighted PM emission value with fuel additive is about 22.7% higher than that without fuel additive. Since, the measurements with fuel additive were carried out after 11 days the engine operated with fuel additive. The time may not be enough for the fuel additive to clean up the tanks and piping systems, completely.

Figure 11 shows the O_2 concentration values with/without fuel additive for different loads. As can be seen from the Figure, O_2 concentration decreases as the engine load increases. The weighted average O2 concentration increased by about 6.5% when the the fuel additive is used.

The weighted average emissions of NOx, SO2, CO_2, CO, O2, HC and PM with/without fuel additive are presented in Figure 12. The results show that the fuel additive reduces the weighted average emissions of NOx, SO_2, CO_2, CO and HC by about 24.8%, 54.5%, 22.9%, 17.4% and 12.2%, respectively. However, the weighted average emission of PM and O_2 concentration increase by 22.7% and 6.5% when the engine operated with fuel additive.

Figure 13 presents the brake specific fuel-oil consumption with and without fuel additive for different loads. Table 5 shows the brake specific fuel-oil consumption for different operations. The fuel additive reduces the brake specific fuel-oil consumption for all the engine loads. The weighted average brake specific fuel-oil consumption is reduced by about 22.6% when the fuel additive is used. The maximum reduction in the brake specific fuel-oil consumption is 46% and it occurs at 25% load (see, Figure 13 and Table 5). The results show that the fuel additive has significant effect on the fuel consumption.

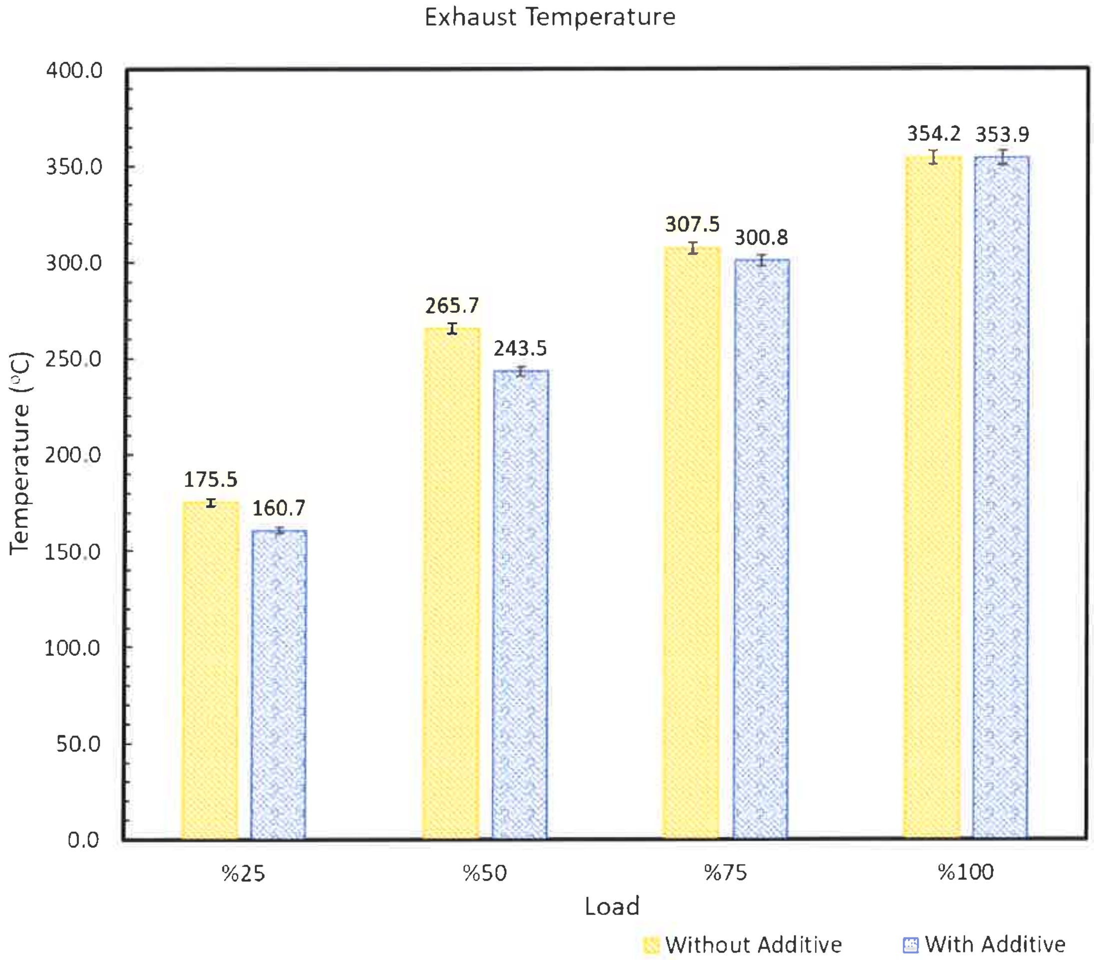

Figure 3. Exhaust temperatures at different loads for the fuel with/without additive .

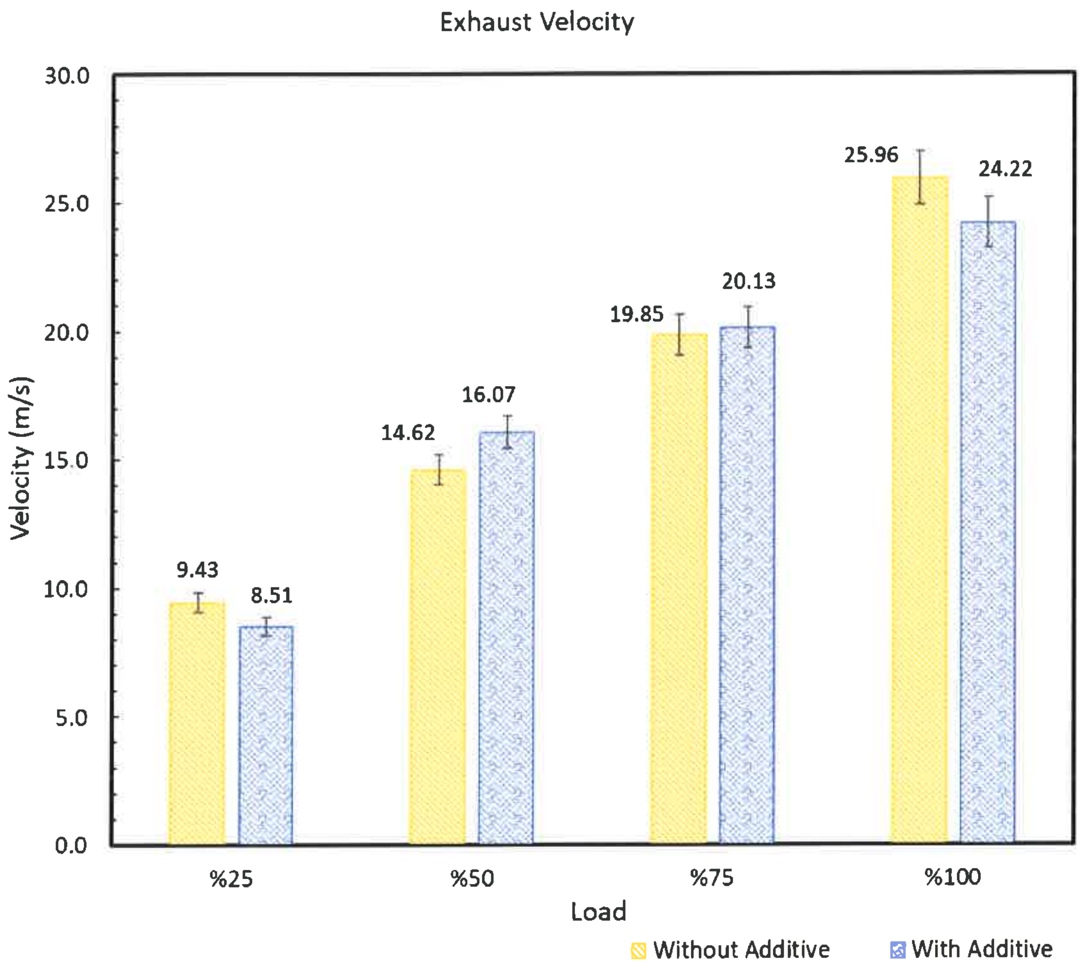

Figure 4. Exhaust velocity at different loads for the fuel with/without additive.

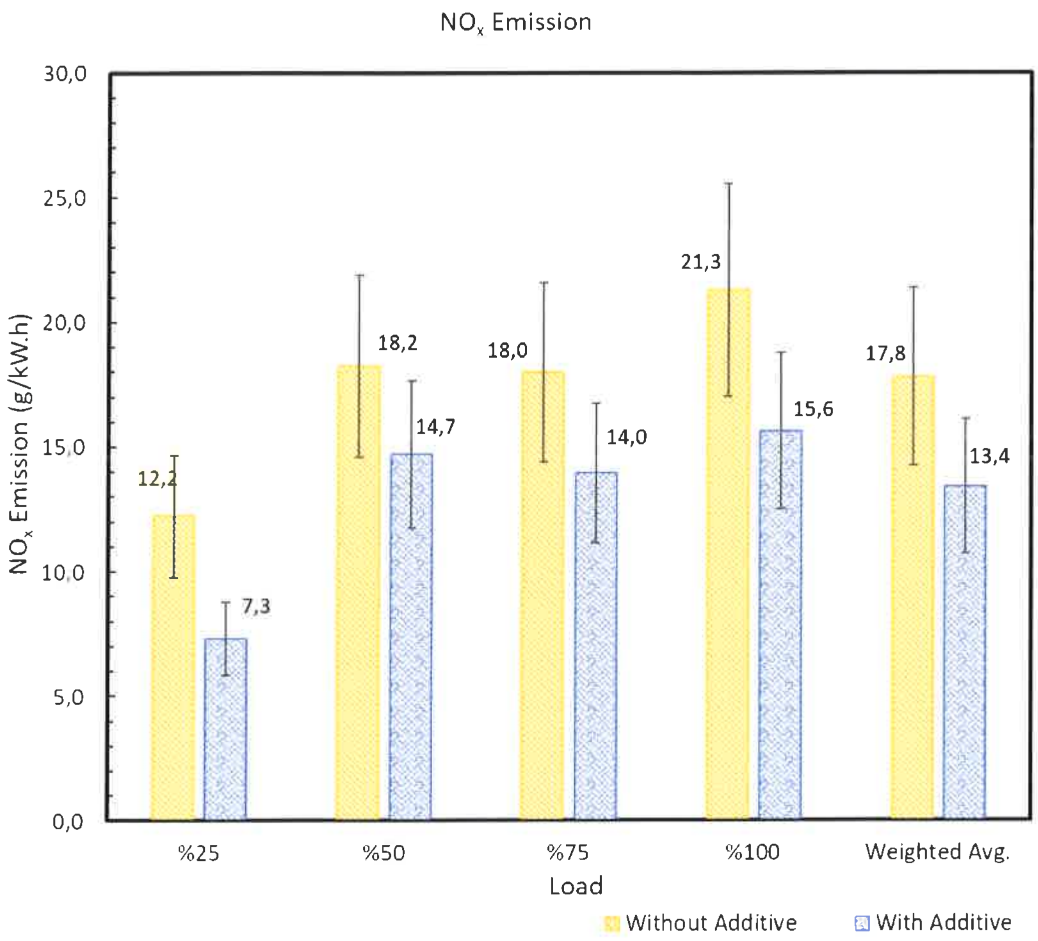

Figure 5. NOx emission values with/without fuel additive at different loads.

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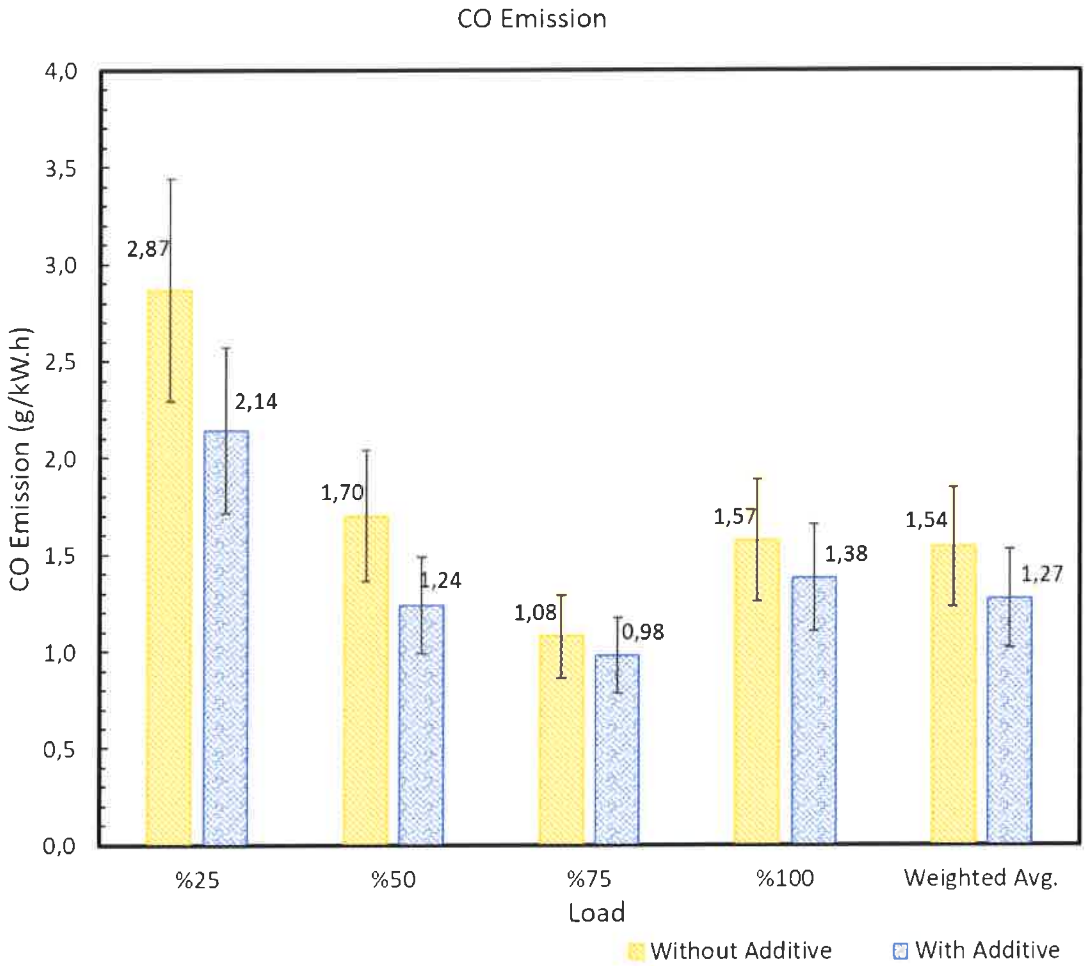

Figure 6. CO emission values with/without fuel additive at different loads.

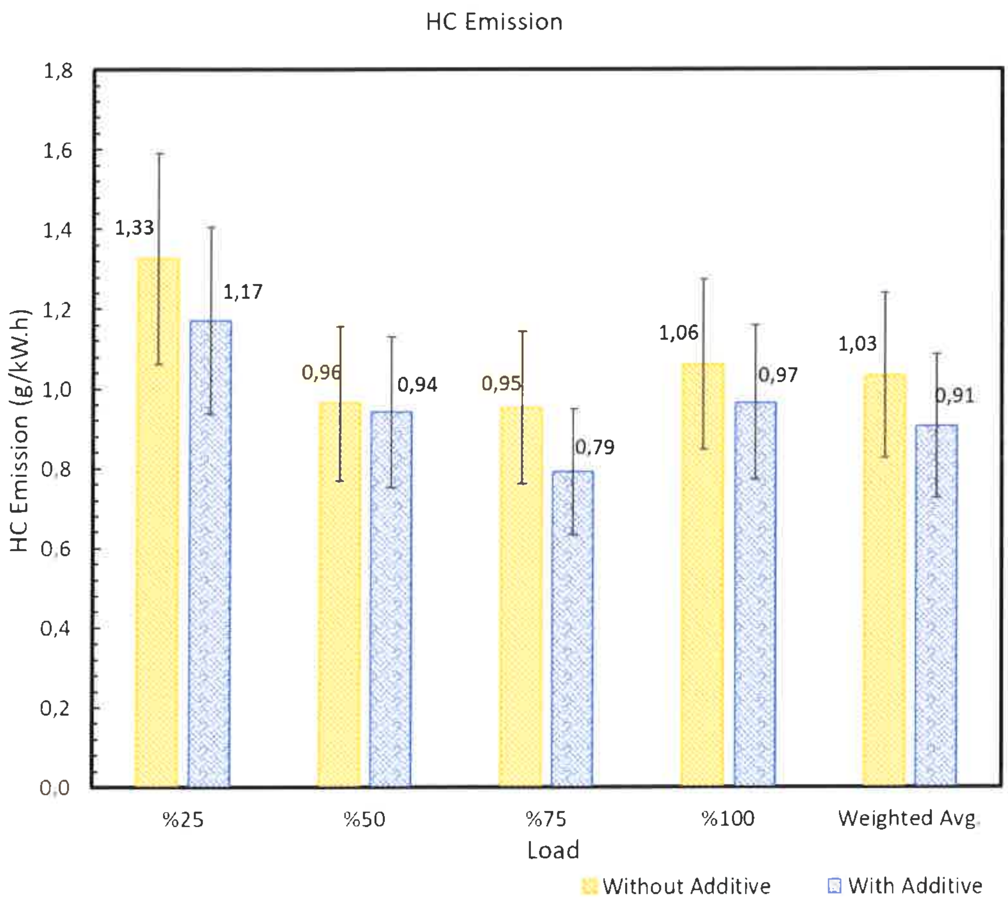

Figure 7. HC emission values with/without fuel additive at different loads.

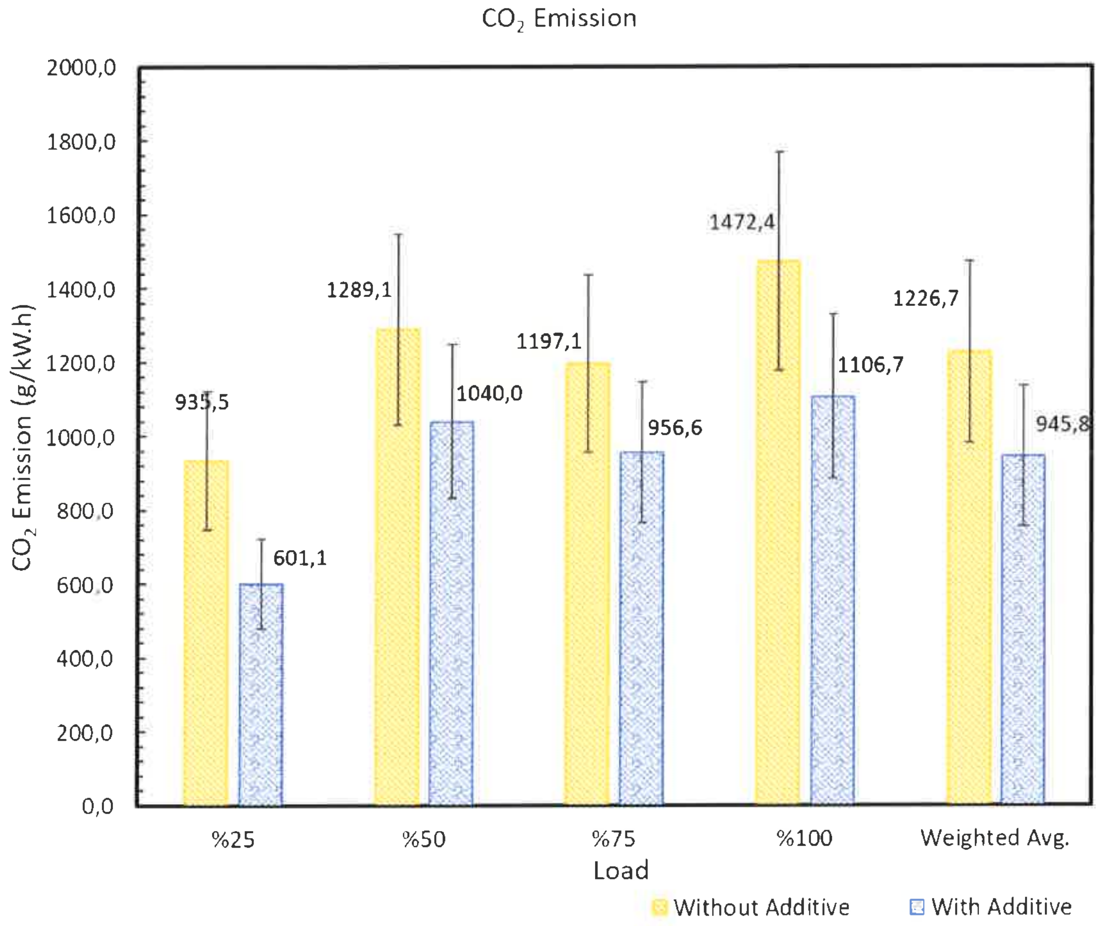

Figure 8. CO_2 emission values with/without fuel additive at different loads.

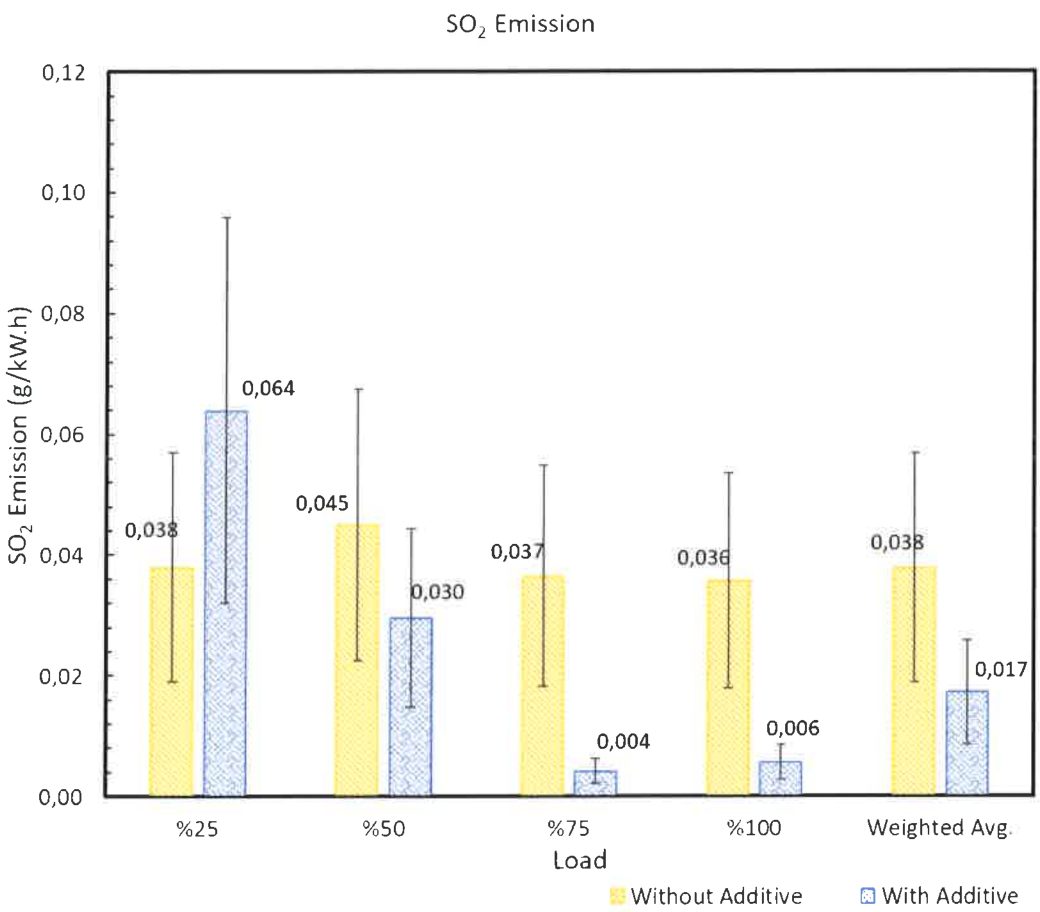

Figure 9. SO_2 emission values with/without fuel additive at different loads.

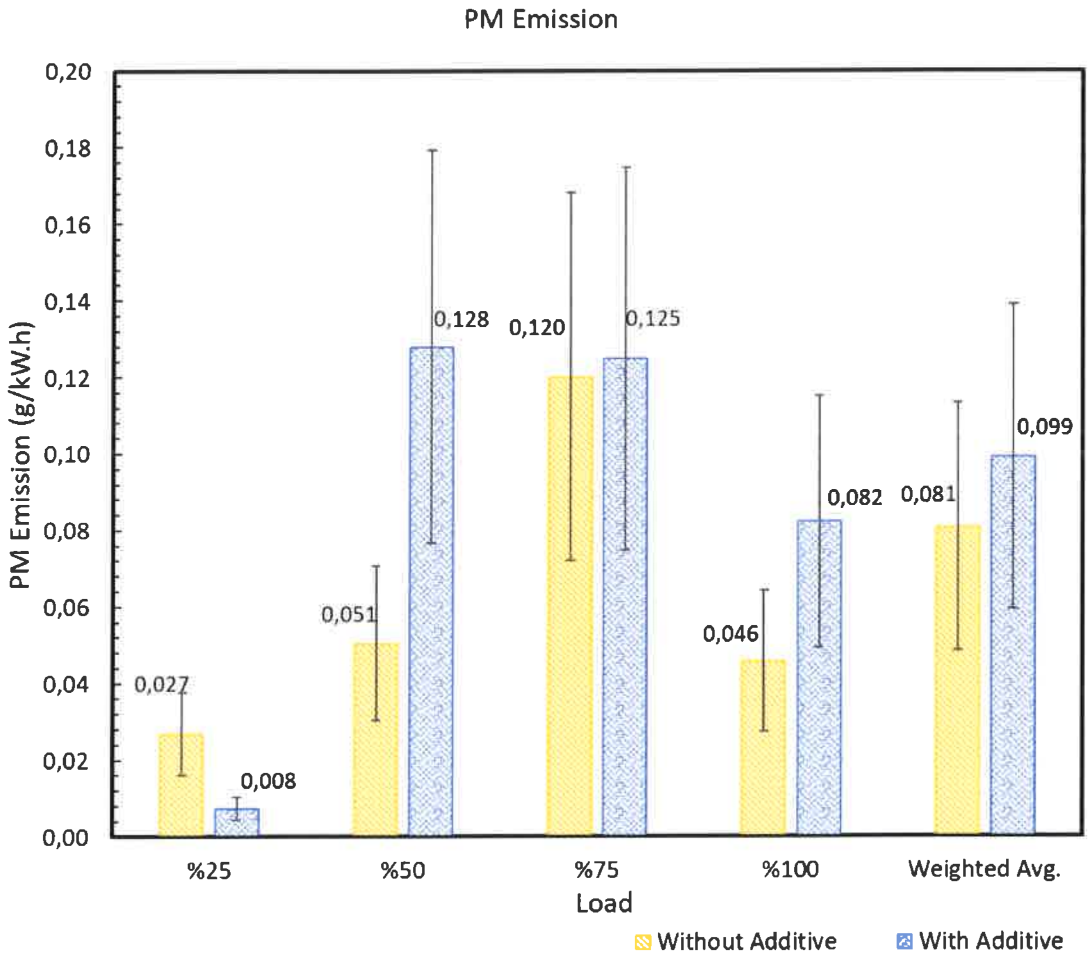

Figure 10. PM emission values with/without fuel additive at different loads.

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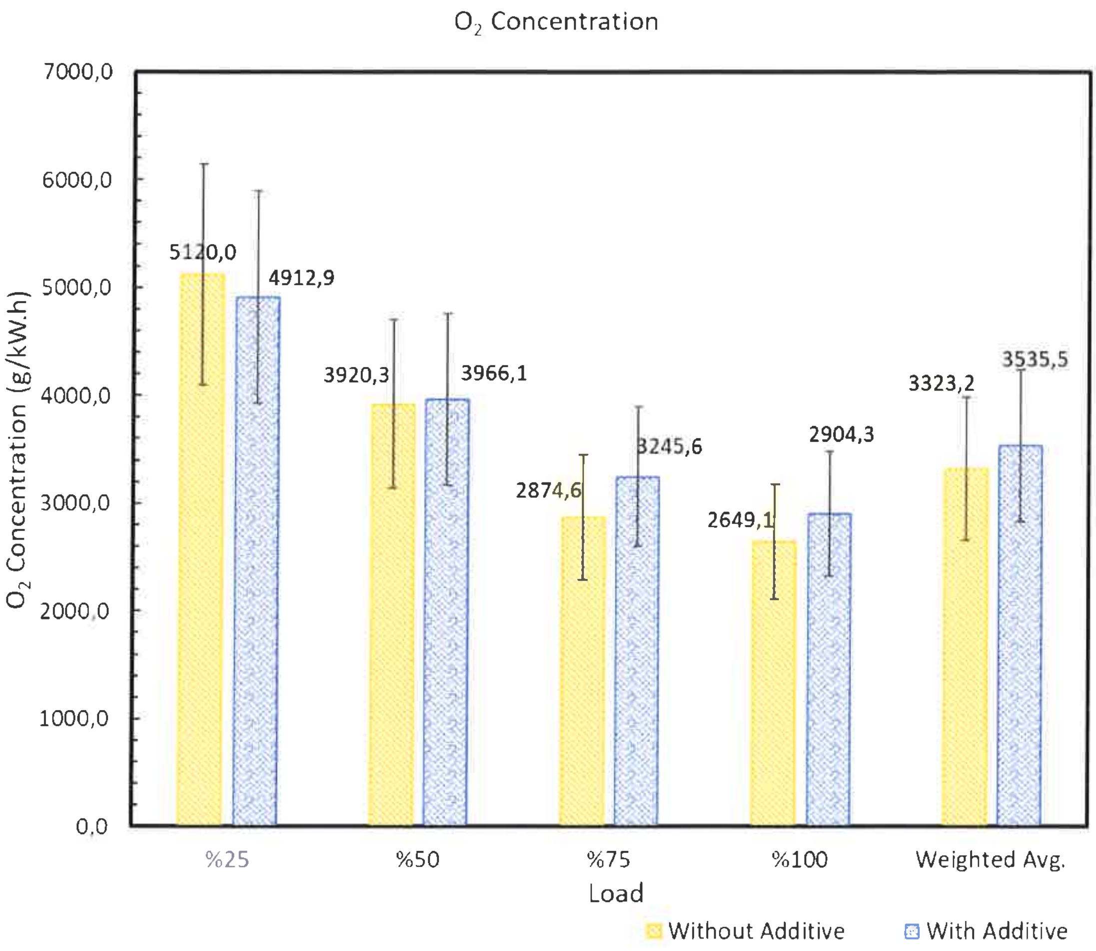

Figure 11. O_2 concentration values with/without fuel additive at different loads.

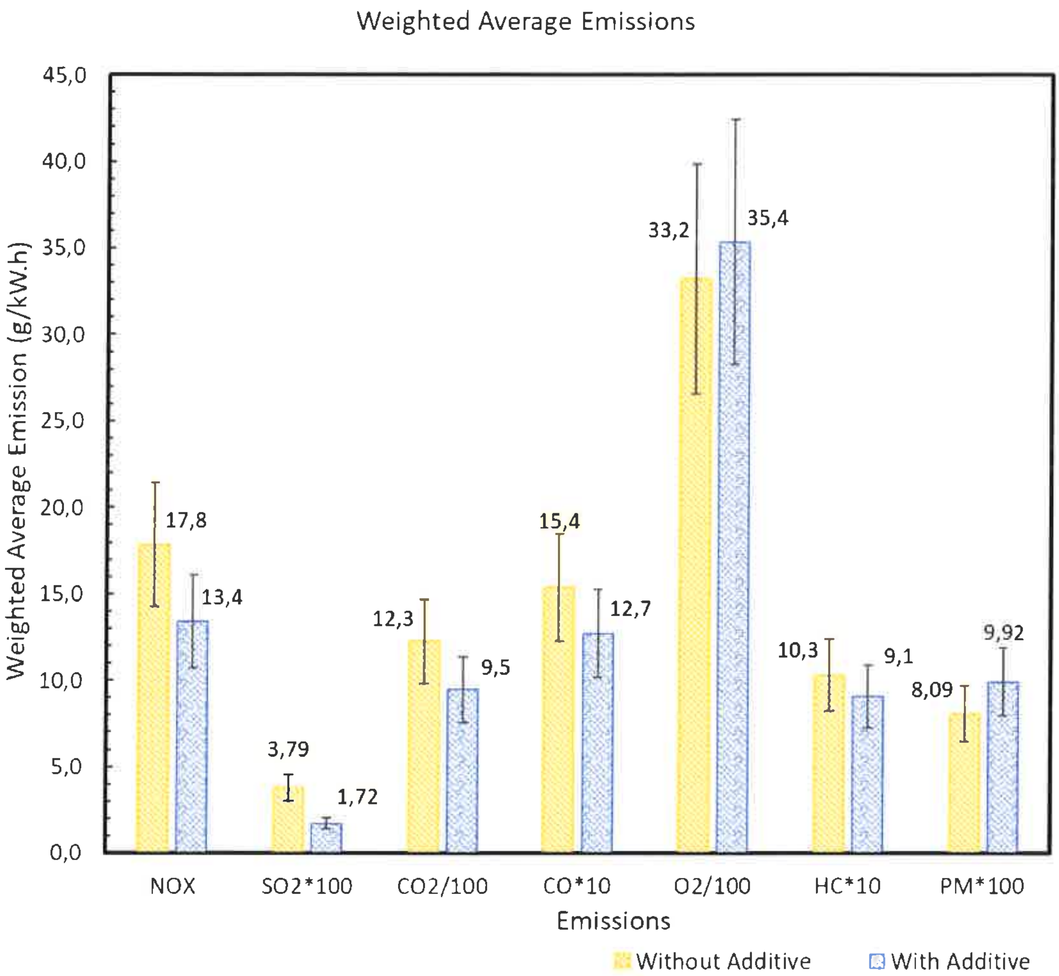

Figure 12. Weighted average emissions with/without fuel additive.

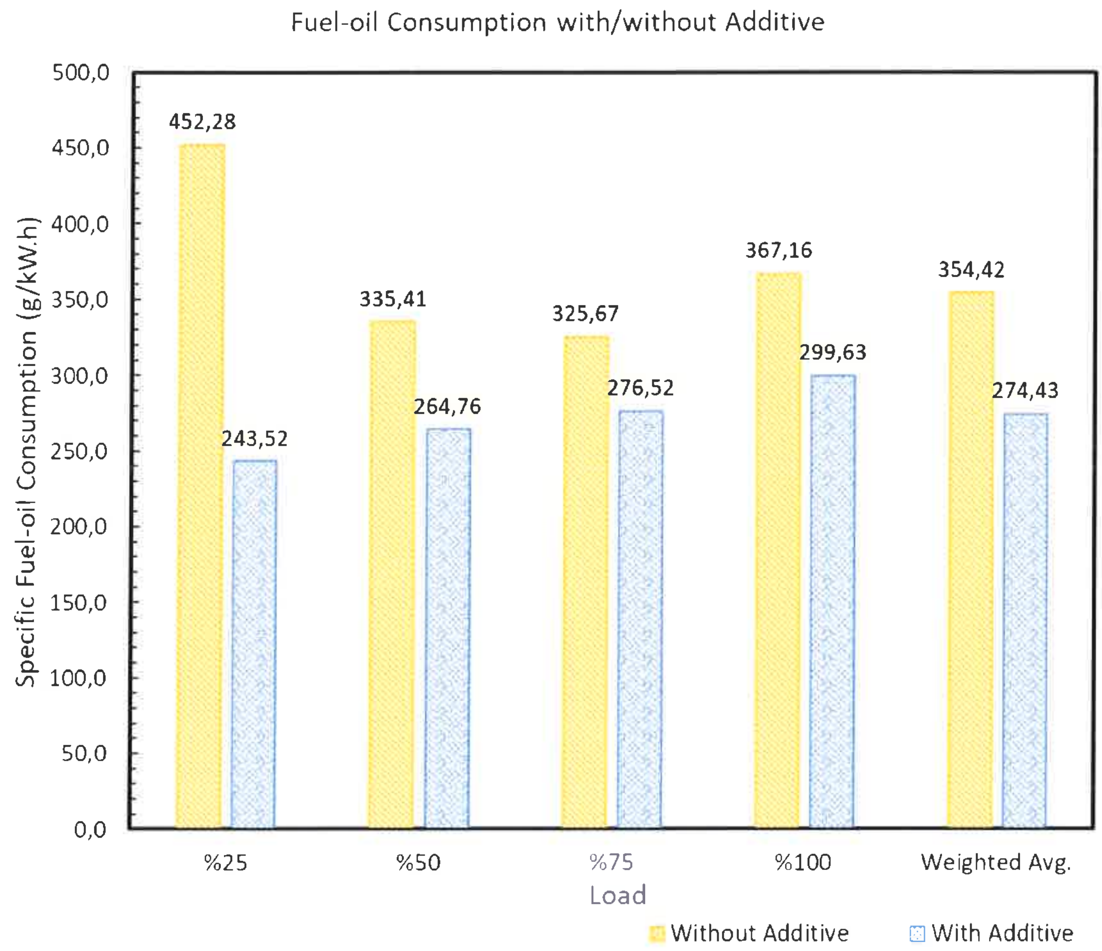

Figure 13. Brake specific fuel-oil consumption with/without fuel additive at different loads.

Table 5. Brake specific fuel-oil consumption for different ferry operations.

Brake specific fuel-oil consumption (g/kW.h)			
Load	**Without fuel Additive**	**With fuel Additive**	**Change (%)**
Idle	690.30	614.45	10.99
Cruise	356.53	263.34	26.14
25%	452.28	243.52	46.16
50%	335.41	264.76	21.06
75%	325.67	276.52	15.09
100%	367.16	299.63	18.39
Weighted Average	354.40	274.43	22.57

4. CONCLUSIONS

The study presents the the effects of fuel additive CleanBoost Gold on the performance and exhaust emissions of a marine diesel engine installed on a ferry. The measurements were carried out on-board of the ferry, Ord. Prof. Ata Nutku sailing between Eskihisar and Topçular at Marmara Sea, Turkey in accordance with the regulations of MARPOL Annex VI, NOx Technical Code.

The weighted emission factors of NOx, SO_2, CO, CO_2, HC and PM emissions for the main engine of the ferry without fuel additive are obtained as 17.8, 0.0379, 1.54, 1230, 1.03 and 0.0809 g/kWh, respectively. The weighted emission factors with fuel additive are obtained as 13.4, 0.0172, 1.27, 950, 0.91 and 0.092 g/kWh, respectively. As can be seen from the results, the use of fuel additive resulted in lower emissions of NOx, SO2, CO, CO2 and HC by 24.8%, 54.5%, 17.4%, 22.9 and 12.19%, respectively. There is an increase in the PM emissions by 22.7% and O_2 concentration increased from 3320 g/kWh to 3540 g/kWh by 6.4%. However,

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the SOx and PM emissions in the exhaust are very low. This is due to using ultra-low-sulfur content fuel. Substantial reductions, especially in the NOx emissions, are obtained with using the fuel additive.

The results show that there is significant reduction in the brake specific fuel-oil consumption, when the fuel additive is used. The brake specific fuel-oil consumption with fuel additive is reduced by about 46.2%, 21.1%, 15.1% and 18.4% for the engine loads of 25%, 50%, 75% and 100%, respectively. On the other hand, the weighted average brake specific fuel-oil consumption is reduced by about 22.6%.

It can be concluded that the fuel additive, CleanBoost Gold improves the combustion process and decreases the NOx, CO, CO_2 and unburned HC emissions and brake specific fuel-oil consumption, substantially. Reducing fuel-oil consumption and exhaust emissions will not only provide financial benefit for the ship operators, but also make positive environmental and health impacts.

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MT

Ca

Sö

Appendix A. The properties of the ULSD fuel with/without fuel additive.

MT

Cl   SÖ

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THE SCIENTIFIC AND TECHNOLOGICAL RESEARCH COUNCIL OF TURKEY
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AB-0378-T
4599
09-19

ANALYSIS REPORT
(Industrial Services)

Report no : 35487319-125.05-823-**4599**

Report date : 05.09.2019

Requested by : Restore Solutions, Inc. Chuck Rice President

Address : 3198 Royal Lane Suite 207 Dallas, Texas 75229

Subject : Petroleum Product Analysis

The results in this report are valid only for the analyzed samples.

Approved by

Dr. Çiğdem TIRIS
Industrial Services Responsible of Energy Institute

This report and results can not be used for commercial and advertisement purposes by the demanding enterprise or its customers. Complete or part of this report cannot be copied or published.

The marked (*) analyses are accredited. Analysis reports without authorized signature are not legitimate.
Energy Institute accredited by TÜRKAK under registration number AB-0378-T for TS EN ISO/IEC 17025:2012 as Calibration Laboratory" Turkish Accreditation Agency (TURKAK) is a signatory to the European co-operation for Accreditation (EA) Multilateral Agreement (MLA) and to the International Laboratory Accreditation Cooperation (ILAC) Mutual Recognition Agreement (MRA) fort he recognition of calibration certificates.

The Turkish Accreditation Agency (TURKAK) is signatory to the multilateral agreements of the European co-operation for the Accreditation (EA) and of the International Laboratory Accreditation (ILAC) for the Mutual recognation of test reports.

The test and/or measurement results, the uncertainties (if applicable) with confidence probability and test methods are given on the following pages which are part of this report

This report is prepared as two originals (one for the customer, one for the institute archives) and contains 3 pages.

T.C. ÇEVRE VE ŞEHİRCİLİK BAKANLIĞI

SÖ MT

TÜBİTAK MAM

AB-0378-T
4599
09-19

Report no : 35487319-125.05-823-**4599**
Requested by : Restore Solutions, Inc. Chuck Rice President
Address : 3198 Royal Lane Suite 207 Dallas, Texas 75229

Sample : Gasoil
Number of samples : 2
Sample handling : By Customer
Condition of sample at reception: Unsealed and Conditional

Expiry date : -
Institute sample register no: 19/379/1-2
Reception date and time : 04.09.2019
Date of the analysis : 05.09.2019

Information on retention samples:
( ) Sample returned to the customer ( ) Retention sample available (x) Retention sample is not taken

19/379/1 : Mehmet AKİF

Parameter	Unit	Limits		Result	Measurement Uncertainty	Method
		Min.	Max			
*Cetane number	-	51,0	-	53,6	0,5	EN SO 5165
*Cetane index	-	46,0	-	51,7	0,4	EN ISO 4264
*Density at 15 °C	kg/m³	820,0	845,0	840,6	0,1	EN ISO 12185
*Polycyclicaromatic hydrocarbons	% (m/m)	-	8,0	1,9	0,1	EN 12916
*Sulfur content	mg/kg	-	10,0	7,4	0,5	EN ISO 20846
*Manganese content	mg/l	-	2,0	<0,5	-	EN 16576
*Flash point	°C	>55,0	-	69,5	2,0	EN ISO 2719
*Carbon residue (on 10 % distillation residue)	% (m/m)	-	0,30	<0,1	-	EN ISO 10370
*Ash content	% (m/m)	-	0,01	0,001	0,0002	EN ISO 6245
*Water content	% (m/m)	-	0,020	0,0044	0,0004	EN ISO 12937
*Total contamination	mg/kg	-	24	<12	-	EN 12662
*Copper strip corrosion (3 h at 50 °C)	rating	class 1		1a	-	EN ISO 2160
*Fatty acid methyl ester (FAME) content	% (V/V)	-	7,0	0,06	0,002	EN 14078
*Oxidation stability	g/m³	-	25	1	0,3	EN ISO 12205
*Lubricity, wear scar diameter (WSD) at 60°C	µm	-	460	330	27	EN ISO 12156-1
*Viscosity at 40 °C	mm²/s	2,00	4,50	2,986	0,013	EN ISO 3104
*Distillation						EN ISO 3405
% (V/V) recovered at 250 °C	% (V/V)		< 65	32,3	1,0	
% (V/V) recovered at 350 °C	% (V/V)	85		92,6	0,8	
95 % (V/V) recovered at	°C		360	359,6	4,3	
*CFPP	°C	-	+5 Summer -15 Winter	-5	0,9	EN 116

Notes:

Authorized Signatures:

53398

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AB-0378-T
4599
09-19

TÜBİTAK

MAM

Report no : 35487319-125.05-823-**4599**
Requested by : Restore Solitions, Inc. Chuck Rice President
Address : 3198 Royal Lane Suite 207 Dallas, Texas 75229

19/379/2 : KATKILI

Parameter	Unit	Limits Min.	Limits Max	Result	Measurement Uncertainty	Method
*Cetane number	-	51,0	-	53,3	0,5	EN SO 5165
*Cetane index	-	46,0	-	51,5	0,4	EN ISO 4264
*Density at 15 °C	kg/m³	820,0	845,0	840,6	0,1	EN ISO 12185
*Polycyclicaromatic hydrocarbons	% (*m/m*)	-	8,0	1,9	0,1	EN 12916
*Sulfur content	mg/kg	-	10,0	7,5	0,5	EN ISO 20846
*Manganese content	mg/l	-	2,0	<0,5	-	EN 16576
*Flash point	°C	>55,0	-	68,5	2,0	EN ISO 2719
*Carbon residue (on 10 % distillation residue)	% (*m/m*)	-	0,30	<0,1	-	EN ISO 10370
*Ash content	% (*m/m*)	-	0,01	0,001	0,0002	EN ISO 6245
*Water content	% (*m/m*)	-	0,020	0,0048	0,0004	EN ISO 12937
*Total contamination	mg/kg	-	24	<12	-	EN 12662
*Copper strip corrosion (3 h at 50 °C)	rating	class 1		1a	-	EN ISO 2160
*Fatty acid methyl ester (FAME) content	% (*V/V*)	-	7,0	0,06	0,003	EN 14078
*Oxidation stability	g/m³	-	25	1	0,4	EN ISO 12205
*Lubricity, wear scar diameter (WSD) at 60°C	µm	-	460	330	27	EN ISO 12156-1
*Viscosity at 40 °C	mm²/s	2,00	4,50	2,979	0,013	EN ISO 3104
*Distillation						EN ISO 3405
% (*V/V*) recovered at 250 °C	% (*V/V*)		< 65	33,0	1,1	
% (*V/V*) recovered at 350 °C	% (*V/V*)	85		94,4	0,8	
95 % (*V/V*) recovered at	°C		360	351,8	4,2	
*CFPP	°C	-	+5 Summer -15 Winter	-5	0,9	EN 116

Summer: 16 March to 15 October inclusive

Winter: 16 October to 15 March inclusive

Notes:

Authorized Signatures:

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